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A GIS Based Tool for Extracting Shoreline Positions from Aerial Imagery (*BeachTools*)

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PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein presents *BeachTools*, an ArcView™ 3.x Geographic Information Systems (GIS) extension designed to identify and quantitatively establish the position of the shoreline and other coastal features from aerial imagery.

BACKGROUND: Aerial imagery, i.e., digitized aerial photography, is commonly analyzed to qualitatively and quantitatively study the evolution of coastal inlet geomorphology. Methodologies for calculating sediment budgets and analyzing inlet-ebb shoal evolution based upon data derived from aerial photography can be found in CETN-IV-15 (Rosati and Kraus 1999) and CETN-IV-13 (Stauble 1998), respectively. *BeachTools* is designed to facilitate such studies by providing a suite of tools that allows for the automatic delineation of coastal features and the generation of baselines and transects, removing the tedium and subjectivity of extracting data by hand, and allowing for much greater precision of such measurements.

Capabilities of *BeachTools* presently include the following:

- Clipping and mosaicing imagery
- Image histogram stretching
- Automatic delineation of coastal features, including a suite of editing tools
- Calculation of aerial extents of coastal features
- Tools for baseline and transect generation of text files containing transect measurements for export to other software

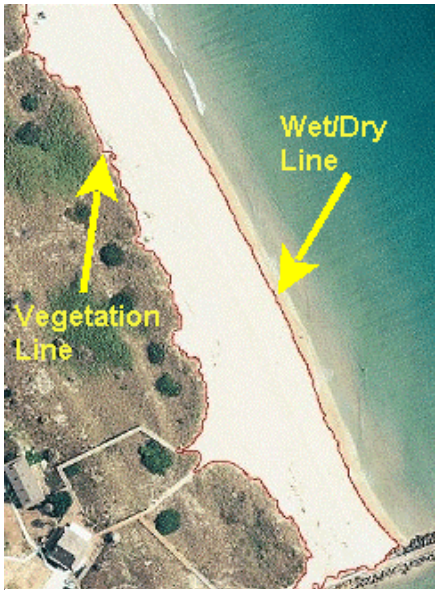

Figure 1. Example of vegetation line and wet/dry line delineated by a vector polygon

The extension was originally developed as a tool for studying historical shoreline change from aerial photography; specifically, to automatically map the wet/dry line and the vegetation line of the beach (Figure 1), and generate transects from a standardized baseline to these features. CETN-II-39 (Kraus and Rosati 1997) discusses the interpretation of shoreline-position data for coastal engineering analysis. The definition of the shoreline must be made explicit and accounted for if shoreline-position data derived through different methods are to be compared. The following sections follow a recommended procedure for extracting shoreline measurements from aerial photo sets.

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14. ABSTRACT

This Coastal and Hydraulics Engineering Technical Note (CHETN) presents BeachTools, an ArcView 3.x Geographic Information Systems (GIS) extension designed to identify and quantitatively establish the position of the shoreline and other coastal features from aerial imagery.

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The vegetation line is a valuable additional indicator of shoreline position. Previous studies have identified the wet/dry line as an estimation of the low tide terrace (Dolan et al. 1980; Smith and Zarillo 1990). Not only does the vegetation line provide an estimate of the position of the toe of the dune, it may be a less variable indicator of long-term shoreline change. Because the response of the vegetation line to erosion or accretion is on the order of months to years, rather than the higher frequency changes of the wet/dry lines, it can act as a low-pass filter, making longer-term trends in shoreline position more apparent. In a case study at Sebastian Inlet, FL, the standard deviation of the elevation of the vegetation line, determined by finding the intersection points with concurrent beach profiles on five separate surveys, was found to be less than half the standard deviation of the wet/dry line elevations, 0.48 and 1.02 m (1.6 and 3.35 ft), respectively. Additionally, the simultaneous estimation of the position of the low-tide terrace and the toe of the dune can be extrapolated to other measurements, such as mean beach width and mean beach slope.

Although *BeachTools* was developed for extracting shoreline measurements, it is not restricted to measuring linear features. The method presented in the following sections simply serves to familiarize the user with its functions. The generation of vector polygons from imagery has a variety of other applications, including the automated mapping of barrier spits and inlet flood and ebb shoals as conducted under the Coastal Inlets Research Program (CIRP) of the U.S. Army Corps of Engineers (USACE). The calculation of aerial extents (area) has been included to facilitate the measurement and extrapolation to sediment volumes of these features.

OVERVIEW – INSTALLING *BEACHTOOLS* AND A SUGGESTED ANALYSIS METHOD:

Installing *BeachTools*: The file *BeachTools*.avx must be placed in ArcView's extension directory ($EXT). Like other ArcView extensions, *BeachTools* is loaded into an ArcView project by selecting *BeachTools* in the extension dialog box. Refer to ArcView help on how to load extensions. *BeachTools* depends on ArcView's ImageAnalyst Extension, so ImageAnalyst is automatically loaded along with *BeachTools*. Image Analyst must already be installed. Loading the *BeachTools* extensions adds the menus and buttons in Figure 2 to ArcView's View Documents.

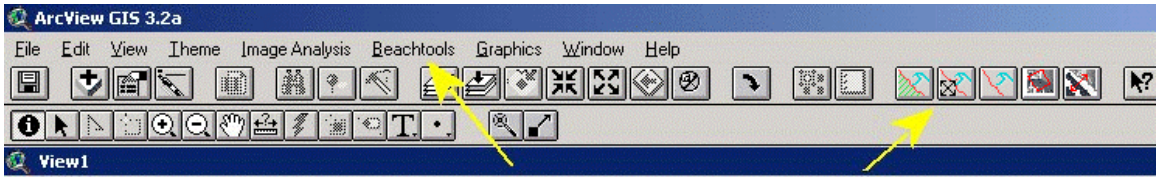


Figure 2. The menu and buttons added on loading the *BeachTools* extensions

Suggested Method for Shoreline Analysis: Although *BeachTools* can manipulate data imported from other sources and can perform functions other than shoreline analysis, the following procedure to map vegetation and wet/dry lines is recommended, especially for the user not familiar with ArcView s environment:

a. Rectify (georeference) imagery using the *ImageAnalyst* extension's *align* tool

b. Subset (clip) imagery using the *Subset Images Tool*, so that adjoining images "fit" together well without large differences in shoreline position on the edges of the adjoining images. (Don't mosaic!)

c. Apply *Toggle Image Legend* to better discriminate the position of the vegetation line and wet/dry lines through histogram stretching of pixel values

d. Create polygons representing the beach from the vegetation line to the wet/dry line using the *Shoreline Polygon Tools*. Union (merge) adjoining or overlapping polygons together.

e. Define a baseline and a transect spacing in *Baseline/Transect Properties.*

f. Generate transects for the baseline-normal position of the wet-dry line and the vegetation line using *Generate Transects*.

More detailed information of each of these steps is given in subsequent sections, as well as some *BeachTools* functions not mentioned here.

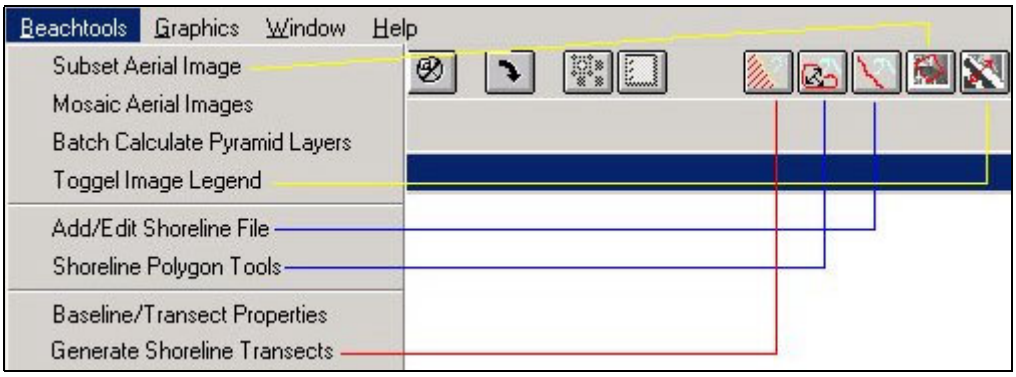


Figure 3. *BeachTools* menu commands and corresponding buttons

Rectifying Aerial Photography: *BeachTools* itself offers no tools for the rectification of an image to a map projection. The *ImageAnalyst align* tool is recommended for this. Please refer to *ImageAnalyst* extension help on the use of the *align* tool.

If the *ImageAnalyst align* tool is used to rectify the imagery it should be used in conjunction with the *BeachTools' Subset* tool (See next section).

If imagery that has already been rectified is to be added, make sure to add it as *ImageAnalysis themes*, not as *Image theme*.

For accurate calculations of shoreline polygons, transects, etc. it is essential to set the View's *Map Units* found in the *View→ Properties* menu, to match the units of the map projection used in the rectified aerial photography (i.e., U.S. state plane projections are typically given in U.S. survey feet.) You will be prompted by several of *BeachTools* functions if map units are not set, but it is essential to select the correct map units.

IMAGE MANIPULATION TOOLS:

Batch Calculate Pyramid Layers: Pyramid *layers* are data decimation files that allow for quick screen redraws. Data are only drawn to the screen at about screen resolution, rather than full image resolution (when zoomed in, the image still displays its full resolution).

Batch Calculate Pyramid Layers provides a file dialog to select multiple image files to calculate their pyramid layers before they are added to a project, or afterward, should the layers become corrupted. This is useful to perform before adding a set of images to an ArcView project or when a batch of pyramid layers become corrupted, etc.

Pyramid layers are highly recommended since shoreline analysis usually involves a lot of panning and zooming. The default image produced by the *Subset* tool (*.img) automatically contains pyramid layers. They have to be written for other existing file formats and can become corrupted when moving or renaming image files.

 ***Subset Aerial Image*:** Immediately after rectification, rather than pressing *ImageAnalyst*s' *save* or *save as* commands, it is recommended that *BeachTools*' *Subset Aerial Image* command be used while the original image is still rectified in memory only. This command allows the user to select and save a rectified clip region, or subset, of the original image, while saving rectification information on the original image, but leaving the original image itself unchanged. There are several reasons for doing this:

- The original image is unchanged, meaning rectification can always be performed again if errors were made, the file becomes corrupted, etc.

- Due to radial distortion, the center of aerial images is generally the most spatially accurate, and since a set of aerial photographs usually have at least 50 percent overlap, only the center region of each image can be selected to be retained

- Selecting only the necessary portion of the image saves disk space.

- *Subset* can be used to create cutlines, i.e., using the *Subset* tool to select areas of adjacent images having similar spectral characteristics limits abrupt changes in adjacent images. This is especially important for creating a visually pleasing mosaic.

- The borders of scanned aerial photography usually contain fiducial marks and other information; it is usually necessary to crop these borders for analysis.

Figure 4. The *Subset* dialog. Only the area under the *Polygon Clip Region* will be written to file

To access the *Subset* tool, make the newly rectified image the active theme, and select *Subset Aerial Image* from the *BeachTools* menu, or the *Subset* button from the button bar. This prompts you to select a file name for the image subset, with a default filename provided. Available file types are *ERDAS IMAGINE (*.img)* and *GEO-TIFF (*.tif)*. The *Subset Mask* dialog then appears, providing tools to select the clip region. Select the top polygon tool to draw the initial clip region directly on the image. The remaining two tools move and vertex edit the polygon. Clicking *Finished* dismisses the dialog and the subset is written to file using cubic convolution. When complete, the new subset is added to the active view, and the user is prompted to remove the original image.

***Mosaic Aerial* Images:** If desired, multiple images clipped using the subset tool can be mosaiced into a single image by selecting *Mosaic Images*. The user is prompted to select images from a file dialog and select the type of mosaicing desired. Images do not have to be present as themes in the current *Arcview*^{tm} Project to be used in a mosaic. The types of mosaicing include:

- #MOSAIC BY ORDER - the pixel values of the top image replace those on the bottom in overlapping areas
- #MOSAIC BY MAXIMUM - the maximum pixel value is used in overlapping areas
- #MOSAIC BY MINIMUM - the minimum pixel value is used
- #MOSAIC BY AVERAGE - the average pixel value is used

For more information on mosaicing types see ArcView's *ImageAnalyst* help. When performing shoreline analysis, it is often better not to mosaic images together. Mosaicing is a lengthy process (depending on CPU) and usually produces a very large file. ArcView maintains the individual images position in the *View* (it looks like a mosaic); it is much more efficient to union the polygons and polylines resulting from the individual images than the images themselves (see Section 4). Additionally, if often becomes apparent that an image's rectification is poor or slightly out of alignment at a later stage of the shoreline analysis. Rectification of individual images can be improved on the fly using the *ImageAnalysis align* tool; if an individual image is not well rectified, the entire mosaicing process may need to be repeated. If desired, however, mosaicing, can produce a visually pleasing composite image.

Toggle Image Legend: This tool changes the brightness and contrast of the current image theme. To add this button to the *View* select *Toggle Image Legend* from the *BeachTools* menu or the respective button on the button bar. When resizing windows, the *Toggle Legend* button on the *View* is sometimes lost. To replace, simply select *Toggle Image Legend* twice.

Finding distinct edges in imagery from the raw pixel values is sometimes difficult, especially along an irregular wet/dry line. Often tonal differences of the raw pixels are small between the dry area of the beach to the wet. *Toggle Image Legend* provides a button directly on the current *View's* display that changes the current active theme (if it is an *ImageAnalysis theme*) from raw pixel values to a stretch of the upper end of available pixel values. The effect of clicking the *Toggle Legend* button on the *View* is the same as moving each band's histogram's minimum and maximum count end points from pixel values of 0 to 255 (raw) to about 173 to 255 (stretched); normally this would require accessing the *ImageAnalysis* theme's legend's advanced options. This is a stretch towards the bright (high raw

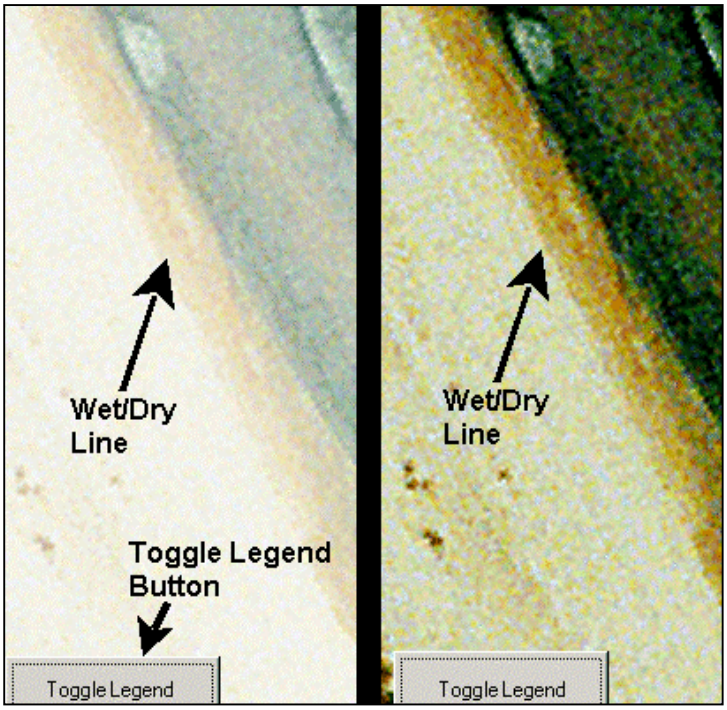


Figure 5. Example of *Toggle Image Legend's* use

pixel values) end of the image spectrum so bright objects (such as the beach) will have much more contrast.

Clicking the *Toggle Legend* button on the *View* makes it easier to see the shoreline's wet/dry line, which makes it easier to create and edit the polygon shoreline file (see next section) and can sometimes make it easier to find edges of corners, etc. that may denote ground control points (GCP's) needed for rectification. Clicking *Toggle Legend* again returns the values to the original "raw" values.

Vector Shapes from Images - Foreshore Identification:

 ***Add/edit* shoreline file:** Selecting *Add Shoreline File* from the *BeachTools* menu brings up a dialog prompting the user to either *Create a New Shoreline File* or *Edit an Existing Shoreline File*.

Create a New Shoreline File prompts the user to select *polygon* or a *polyline* theme for the shoreline type. This command is similar to the *New Theme* command on ArcvView's *View* menu, except that the theme added is not temporary, polylines and polygons outlines are always red with no fill, and the theme is put into edit mode. A polygon theme should be selected if the shorelines (or other objects) are to be identified using *Shoreline Polygon Tools* (see next section). Polylines are typically better for manual identification of the shoreline (i.e., delineating objects with a mouse).

Edit Existing Shoreline File is similar to the *View* menu's *Add Theme* command.

 **Shoreline polygon tools:** This is a set of tools that delineates the dry beach area by means of a clustered supervised classification that creates a contiguous area represented by a polygon. Creating a vector polygon representing the backshore, from vegetation line to wet/dry line (an estimate of the toe of the dune and the low-tide berm, or terrace), using image analysis techniques has several advantages:

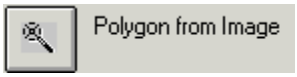
- Both the vegetation line and the wet/dry line are delineated, so area can be determined.
- Traditional methods of drawing/digitizing the wet/dry line manually can be extremely time consuming and very subjective.
- The polygon produced is extremely detailed, necessary for analysis of beach forms, rhythmic topographies, etc.

Selecting *Shoreline PolygonTools* from the *BeachTools* menu starts a dialog containing two groups of tools:

a. Creating: Create vector polygons from imagery

b. Editing: Edit the resulting polygons if necessary

Creating:



The *Polygon from Image* tool facilitates growing a vector polygon that contains a spatially contiguous area of similar pixel values. To operate *Polygon from Image*, a polygon shoreline theme must be present in the *View* and in editing mode (i.e., use *Create* a *New Shoreline File* or *Edit an Existing Shoreline* File). Make the *ImageAnalysis* theme you wish to use for shoreline identification the *active theme* and then select the *Polygon from Image* tool from the *Polygon Shoreline Tools* dialog. With the cursor, select a region of pixels on the backshore that represents other areas by either dragging out a rectangle or selecting a point. This creates a polygon of contiguous similar pixels (this may require some CPU time). By using the *include island polygons* check box, you can either allow the resulting polygon to have holes for anomalous areas or ignore such areas. A reason not to include island polygons would be a case were there are tide lines or weed lines or other objects on the beach these objects should not be identified as holes. A reason to include island polygons would be in analysis of a poor spatial/spectral resolution image where surf zone white water and backshore pixel values are statistically similar (see Figure 6).

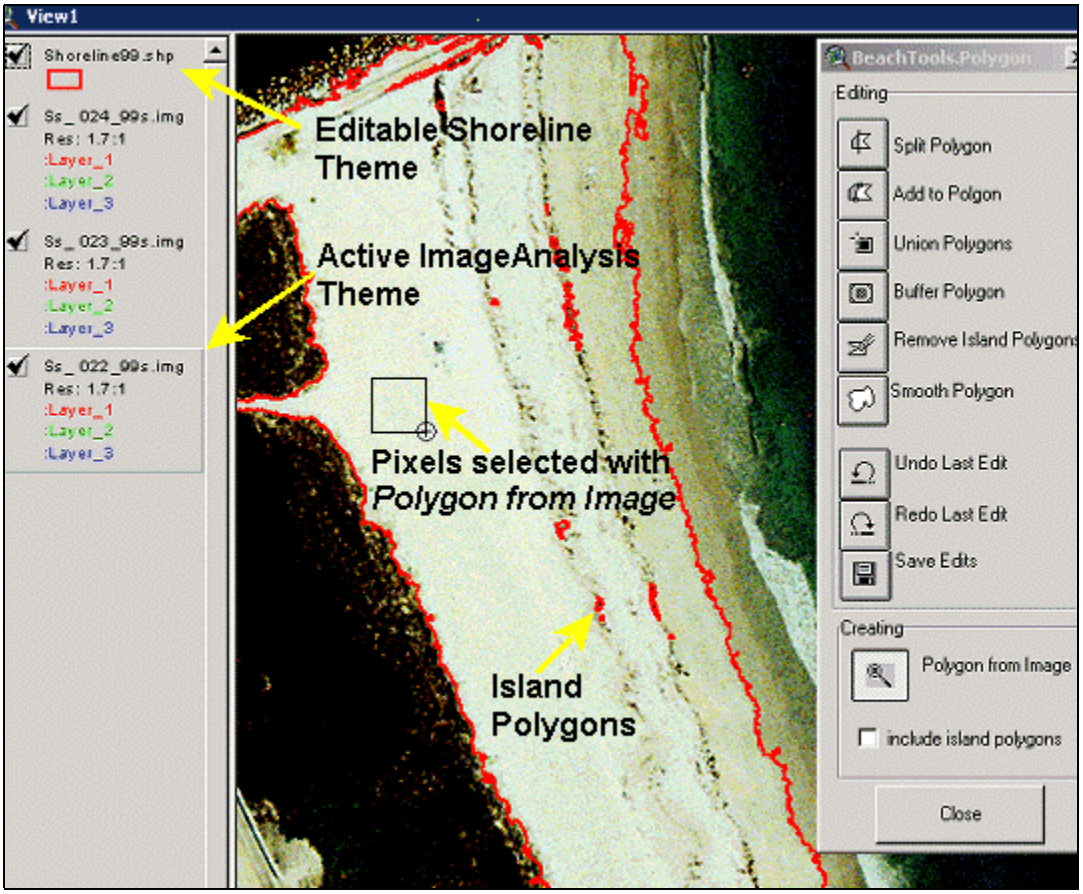


Figure 6. The *Shoreline Polygon Tools* dialog: Using the *Polygon from Image* tool to create a polygon (in red) of the backshore; the *shoreline theme* (Shoreline.shp) is in edit mode, and the *ImageAnalyst theme* in use (Ss_024_99s.img) is the active theme

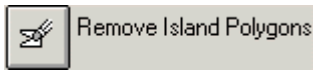
Editing:

The newly created polygon is often extremely complex, with multiple double backs of the perimeter and small finger-like extensions on the perimeters. Sometimes areas of the backshore are spectrally different and separate polygons need to be created and merged. This can make interpretation difficult and can potentially confuse the *Transect Generator* (see next section). Sometimes areas of the backshore are spectrally different and separate polygons need to be created and merged. In general, the better the spatial and spectral resolution of an image, the simpler and better representative the polygon. In any case, the resulting polygon(s) needs to be checked and usually edited to some extent. The *Editing* tools designed are for this purpose. With the exception of *Save Edits* and *Undo Edits*, they all operate only on the currently selected polygon(s). Select or deselect a polygon by clicking on it. (Select more than one by holding the shift key or by dragging a box around the area.)

This tool chops out unwanted areas or features. This is often necessary if the newly created polygon follows a sandy path or boardwalk some distance from the beach, or when the polygon accidentally selects some white water in the surf zone. The end points of the polyline used to define the chop must be to the exterior of the polygon. The polyline splits the original polygon into two; select the unwanted polygon and press delete on the keyboard.

Add to Polygon adds areas of features that were missed. This may happen if a long boardwalk extends into the backshore region, a debris line crosses the wet/dry line, etc. The end points of the polyline used to define the *add to* region must be in the interior of the polygon. This is usually used in conjunction with *Union Polygons*; add a little bit to a larger polygon and merge them together.

Merges polygons together. Lines where contiguous polygons meet disappear. This tool should be selected wherever overlapping or contiguous polygons meet, i.e., in areas of overlapping imagery, after using the *Add to Polygon* tool, or if dissimilar areas must be individually selected. Only selected polygons will be unioned.



Gets rid of holes in the interior of the polygon. These are often created if two overlapping polygons are merged and are always created when the *include island polygons* check box is checked in using the *create polygon* tool. The user is prompted for the size of the filter each time it is run, the size is the number of nodes in the polygon. Final polygons should be completely free of interior holes or island polygons.

It is almost always necessary to smooth the perimeter using *Smooth Polygon*, which runs an N-sized convolution filter (moving average) around the perimeter. The user is prompted for the size of the filter each time it is run. Only selected polygons will be smoothed.

With good imagery, and a distinct wet/dry line, *Smooth Polygon* is often the only editing necessary to prepare the polygon for unioning with polygons from adjacent images, and

subsequent analysis. With poorer quality imagery, it is sometimes difficult for *Polygon from Image's* algorithm to distinguish between patches of white water, boardwalks, roads that intersect the backshore, etc. It is often necessary to select *include island polygons* in this case, since area of wet sand may be surrounded by areas of white water and dry sand, and use *Split Polygons*, *Add to Polygon*, *Buffer Polygon*, and *Remove Island Polygons* to remove unwanted features, add missed features, and nudge the polygon into proper position. The final polygon should be fairly smooth and contain no island polygons (holes). If any edit produces an undesirable result, use *Undo Edit* (and *Redo Edit)*. It is a good idea to union all overlapping or adjoining polygons from all of the imagery for a given study date by operating the *Union Polygons* tool. This avoids confusion for the *Calculate Transects* algorithm.

Establishing Shoreline Positions – Generating Transects and Baselines:

Once a suitable polygon of the backshore or other areas has been generated, a baseline needs to be added to the view to serve as a stationary reference for generating transects. Baselines and transect properties are defined in the *Baseline*/*Transect Properties* dialog. Transects for any applicable shape file can be generated using the *Generate Shoreline Transects* command, as long as there is a baseline present in the view.

Although the methods in this CHETN recommend a polygon representation of the shoreline, polylines representations are supported as well. In constructing a baseline it is best to make it parallel to and roughly as long or longer than the longest shoreline in the time series of shorelines. For good results with polygon representations, it is important to place the baseline landward of the shoreline polygon and never intersecting the shoreline. This is not an issue with polyline shorelines; baselines can be on either side or intersect them multiple times.

Baseline/transect properties: At the top of the *Baseline Transect Properties* dialog (see Figure 7) is an input for transect spacing, the baseline-parallel distance between consecutive transects. The units for this are always the projection units. The selection of spacing is dependent on the project location and the use of the data; i.e., to capture small-scale features such as beach cusps on the east coast of Florida, spacing on the order of 5 m should be used.

Below transect spacing is an input for a :*switchback's* length. This parameter allows for complex polygon shorelines where a *switchback* or doubleup in the perimeter occurs. All switchbacks smaller in cross-shore distance than the entered length will be ignored. If switchback is set to zero, errors may arise identifying vegetation lines and wet/dry lines when a transect encounters a switchback. This parameter should be set to some number much smaller than the narrowest point of the backshore; usually some small fraction of the transect spacing suffices.

The button *Select Baseline from File* is used to select a baseline from an existing *ArcView* shape file. The path to the baseline selected is displayed below the button. The *OK* button will add the baseline to the view if it does not exist or replace the existing baseline with the newly selected one.

To create a new baseline, select either *Use Polyline Tool* or *Manual Coordinate Entry*. If the polyline tool is selected, draw the position of the baseline directly on the view's display. *Manual*

Coordinate entry is selected for entering the end points of the baseline using known positions in the current map projection as nodes. Up to five nodes are currently supported. When finished using either the polyline tool or manual coordinate entry, click *Finished* and enter a filename for the new baseline. Clicking *OK* dismisses the dialog and adds the newly created baseline to the view (or replaces an existing one).

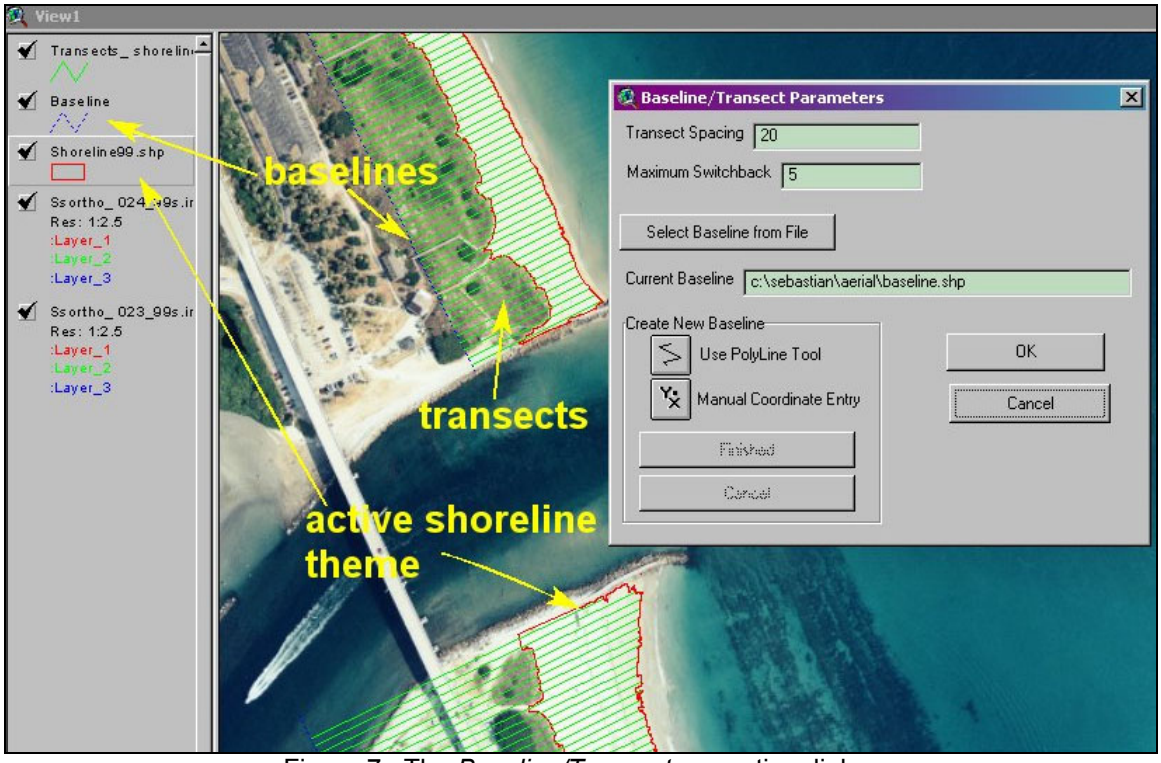


Figure 7. The *Baseline/Transect* properties dialog

Generate shoreline transects: To generate the transects, make the shoreline theme (or other shape) the active theme and select *Generate Shoreline Transects*. This automatically creates the transects, with no further prompting. After transect generation is complete, information on spacing and the number of transects generated is displayed. The transects are added to the view in the form of an *Arcview*^{tm} *shape theme*. The attribute table of this theme contains a transect identifier, a baseline identifier (for multiple baselines), a baseline-vegetation line transect length (*vegLength*), and a baseline-wet/dryline length (*shrLength*). This table can be exported in a variety of formats for analysis with other software.

Other Uses for *BeachTools*: The preceding sections outline application of *BeachTools* specifically for shoreline analysis. As mentioned in the introduction, however, it can also be applied to delineate shoals, spits, and other coastal features. Although the transect calculations are not necessarily useful for other purposes, the inclusion of areas in the polygon attribute tables are included to measure the aerial extent of such other features. Time series of aerial photography can serve to illustrate and monitor the evolution of such features and the inlet system as a whole.

ADDITIONAL INFORMATION: The research discussed herein was jointly supported by two CIRP work units, "Inlet Channels and Adjacent Shorelines" and "Inlet Morphology and Channel Evolution." Questions about this CHETN can be addressed to Mr. Ron K. Hoeke (321 674-7742, e-mail: *rhoeke@fit.edu*) or Dr. Gary A. Zarillo (321-674-7289, e-mail: *Zarillo@fit.edu*). USACE personnel can also contact Dr. Nicholas C. Kraus (601-634-2016, e-mail: *Nicholas.C.Kraus@erdc.usace.army.mil*). This Technical Note should be referenced as follows:

> Hoeke, R. K., Zarillo, G. A., and Synder, M. (2001). "A GIS based tool for extracting shoreline positions from aerial imagery (*BeachTools*)," Coastal and Hydraulics Engineering Technical Note CHETN-IV-37, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
> *http://chl.wes.army.mil/library/publications/chetn/*

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